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Aircraft noise, health, and residential sorting: evidence from two quasi-experiments

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Abstract: We explore two unexpected changes in flight regulations to estimate the causal effect of aircraft noise on health. Detailed measures of noise are linked with longitudinal data on individual health outcomes based on the exact address information. Controlling for individual heterogeneity and spatial sorting into different neighborhoods, we find that aircraft noise significantly increases sleeping problems and headaches. Models that do not control for such heterogeneity and sorting substantially underestimate the negative health effects, which suggests that individuals self-select into residence based on their unobserved sensitivity to noise. Our study demonstrates that the combination of quasi-experimental variation and panel data is very powerful for identifying causal effects in epidemiological field studies.

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1 Introduction

State regulations against noise pollution are a recurring theme on the public policy agenda. On the one hand, such regulations are enforced to reduce the risk of long-term health damages. On the other hand, any attempt to lower the existent levels of noise will inevitably generate costs that have to be internalized. A rich body of cross-sectional research (e.g., Black *et al.*, 2007; Stansfeld *et al.*, 2005; Huss *et al.*, 2010) has analyzed the relationship between aircraft noise and health, mostly finding insignificant results. However, identifying the *causal* effect of noise on health is very difficult empirically, and the previous evidence has not been conclusive in that respect.

The major reason preventing a causal interpretation is the non-random exposure to noise. First, noisy regions differ from quiet ones in unobservable but health relevant aspects other than noise (e.g., the quality of the neighborhood). Second, individuals self-select into residence based on their preferences for quietness and pre-existing health conditions. Noise sensitive and vulnerable people, for example, tend to live in quiet neighborhoods, whereas noise insensitive and resistant people tend to find a better fit in noisier neighborhoods (Mokhtarian and Cao, 2008). If this selection is not accounted for, then there are serious concerns about the internal validity of the stated causal relationships.

This paper aims to estimate the effect of aircraft noise on health using a quasi-experimental identification strategy. First, panel data and fixed effects models are explored to remove time-constant confounders, including both unobserved invididual and spatial heterogeneity related to health. While fixed effects have been successfully applied, for example, in studies that relate air pollution to health (e.g., Neidell, 2004; Coneus and Spiess, 2012), fixed effects have never been used so far to study the effect of aircraft noise on health. Two explanations for this might be that aircraft noise does not vary much over time (in particular on a year-to-year basis), and/or that variations are not exogenous if related to the relocation of individuals (often involving health relevant choices like the change of job or a new personal situation). That is why we secondly, for the first time in this context, combine fixed effects with two quasi-experiments. These quasi-experiments create sufficient exogenous variation in aircraft noise over time for the same person living in the same residence, even after controlling for individual and time fixed effects.[1]

Specifically, we explore two unexpected changes in flight regulations at Zurich airport. Being Switzerland's largest gateway, it operates around 270,000 flights every year distributed on three different runways: directions north/south, northwest/southeast, and east/west (see Figure 1). In summer 2000, the east/west runway had to be closed for two months due to the construction of a new terminal. During this period aircraft started in direction south instead of west. The second, large-scale change happened in 2003. Since the airport is located relatively close to the Swiss-German border, and as a protective measure against noise pollution, the German government issued a binding decree in April 2003 that prohibited landings over their territory in the early morning and late evening. As a response, the *Swiss Federal Office of Civil Aviation* changed the regulations to allow for landings from the south, which had been prohibited before. The new regime, which was enforced in October 2003, determined that early morning aircraft were redirected to land from the south and late evening aircraft from the east (rather than from the north directions).

We estimate the effects of aircraft noise on health using yearly self-reported health data drawn from the *Swiss Household Panel* (SHP), a large and representative panel survey of the Swiss population. We extracted health information on specific domains like sleeping quality, weakness/weariness, and headaches, and on rather general assessments like health status, the number of doctor consultations, and the number of days affected by health problems. Based on spatial coordinates of the individuals' addresses, we linked the health data with detailed continuous and longitudinal aircraft noise data provided by the *Swiss Federal Laboratories for Materials Science and Technology* (EMPA).

Our analyses indicate that cross-sectional studies significantly underestimate the negative

[1]In other areas, for example hedonic studies in environmental economics, quasi-experiments have already become a popular tool to identify causal effects (e.g., Parmeter and Pope, 2009; Greenstone and Gayer, 2009; Boes and Nüesch, 2011). See also DiNardo (2008) for a critical assessment of quasi-experiments in economics and the social sciences in general.

effects of aircraft noise on health. Whereas the association between aircraft noise and health is insignificant and small in the cross-sectional specifications, we find that aircraft noise significantly increases sleeping problems, weariness, and headaches when using individual fixed effects. Using hedonic pricing, we estimate the yearly costs of aricraft noise to be around USD 400 per person living in the Canton of Zurich.

The observation that fixed effects intensify the adverse health effects of aircraft noise strongly indicates that the bias in cross-sectional studies arises from residential sorting based on individual vulnerability and noise sensitivity. As noise sensitive people tend to self-select into quiet regions, the population in quiet regions is negatively selected with respect to pre-existing health inputs, and studies that do not control for this type of residential sorting underestimate the causal effect of noise on health. Individual fixed effects control for a person's noise sensitivity, defined as a *stable* personality trait covering attitudes towards noise and influencing one's reaction to noise, independent of the actual noise level (Nijland *et al.*, 2007).

The remainder of the paper is structured as follows: Section 2 reviews the literature on the effects of noise on health. Section 3 describes the two data sources and how they are linked. Section 4 presents the identification strategy and the results. Section 5 concludes.

2 Related literature

The health effects of noise emerge as a direct consequence of exposure, or indirectly through subjective reactions such as annoyance (Job, 1996). Whereas the exposure to high levels of noise (e.g., above 85 dB(A), A-weighted decibels) and extended durations have immediate consequences on hearing and blood pressure (Talbott *et al.*, 1990), the exposure to moderate levels affects health mainly indirectly via perceived stress. This component in turn is largely determined by the emotional and cognitive evaluation of the stressor, in our case aircraft noise. Thus, the potential health effects of aircraft noise are mainly induced by annoyance, or some other form of negative appraisal. Noise sensitive individuals, for example, experience more stress and annoyance when exposed to noise than noise insensitive individuals who are better able to cope with the noise stimuli (Black et al., 2007; Fyhri and Klaboe, 2009).

In order to identify the causal effect of noise on health, lab experiments are well suited. Previous studies documented adverse effects of nocturnal noise on subjective sleep quality (Elmenhorst *et al.*, 2010) and on blood pressure (Haralabidis *et al.*, 2008). The key advantage of lab experiments is that they enable the researcher to randomly manipulate the noise exposure in a well-controlled environment, which leads to precise estimates of the causal noise-health relationship. Lab studies, however, have two major limitations: First, long-term effects of noise cannot be tested either due to time and money constraints, or because ethics committees would not approve studies that could cause a major health deterioration. Second, the extrapolation of laboratory findings into everyday life situations is critical. In the home environment, people become accustomed to noise over time, also called habituation effects (Griefahn, 2002), and tend to develop coping mechanisms (sleeping with closed windows) that reduce perceived noise nuisance. As study participants tend to pay more attention to noise in the lab, the measured health effects tend to be stronger than in field studies which challenges the external validity (Pirrera *et al.*, 2010). To address the limitations of lab studies, additional field studies on the noise-health relationship are necessary and desired from a policy perspective.

Epidemiological field studies have relied on cross-sectional samples so far. The cumulative evidence from this cross-sectional work is inconclusive. While the studies of Black *et al.* (2008) and Jarup *et al.* (2008) found positive correlations between aircraft noise and hypertension, other cross-sectional studies (e.g., Stansfeld *et al.*, 2005; Huss *et al.*, 2010) found no significant effect on self-reported health and myocardial infarction and strokes.

In correlational field work, it is important to consider the possibility that individuals living in areas highly exposed to noise may have poor health due to the existence of third factors related to health, such as their socio-economic status, or air pollution in the neighborhood (Job, 1996). Most cross-sectional studies include control variables for a person's sex, age, and educational level. Several studies also take a person's socioeconomic status (e.g., income, employment status), lifestyle factors (e.g., smoking, alcohol consumption, intake of fruits and vegetables), or the body mass index into account. Huss *et al.* (2010) shows that the proportion of persons with tertiary education declines with increasing aircraft noise, whereas the proportion of unemployed, people living in old buildings, and foreign nationals increase.

While the just mentioned aspects suggest a positively selected group of people in quiet regions (in terms of health inputs), the direction of selection is not unequivocally determined. Alternatively, one could argue for a negative selection based on noise sensitivity. Noise sensitive people tend to settle in quiet regions, whereas noise insensitive people tend to self-select into noisier and often cheaper regions (e.g., Mokhtarian and Cao, 2008).[2] Such residential sorting will bias the effect of noise on health if noise sensitivity is related to both factors. Previous studies (see Fyhri and Klaboe (2009) for an overview) documented that a person's noise sensitivity is positively associated with components of a pre-morbid personality (e.g., negative affectivity, neuroticism, critical tendency), psychiatric disorders, feelings of exhaustion (weariness, tiredness, faintness), pain in the limbs (back, shoulder, headache), heart problems (heart consciousness, chest pain), and sleeping problems. Thus, there is evidence that noise sensitivity is a confounding variable in the noise-health relationship (Fyhri and Klaboe, 2009).

While some studies (e.g., Babisch *et al.*, 2005; Kishikawa *et al.*, 2009) try to use specific items to measure noise sensitivity (e.g., Weinstein's noise sensitivity scale), we make use of panel data and individual fixed effects. Such a strategy is reasonable given the evidence from human-biological and acoustic research. A twin study of Heinonen-Guzejev *et al.* (2007) shows that noise sensitivity is partly genetically determined. The lab experiment of Ellermeier *et al.* (2001) suggests that varying levels of noise exposure do not affect a person's self-reported noise sensitivity. Hence, using individual fixed effects seems promising to control for a person's unobserved noise sensitivity.

[2] An exception is the study of Nijland *et al.* (2007) that does not find evidence of residential sorting because average noise sensitivity is not significantly related to noise.

3 Data and institutional background

We use two different data sources to construct our linked health-noise dataset. The data on aircraft noise exposure is provided by the *Swiss Laboratories for Materials Science and Technology* (EMPA). The information on health outcomes is drawn from a large and nationally representative panel survey, the *Swiss Household Panel* (SHP). We will consider the two datasets in turn, and then discuss how we linked them.

3.1 Aircraft noise data

We employ model-based continuous noise data provided by the *Swiss Federal Laboratories for Material Science and Technology* (EMPA). The EMPA calculates annual data on aircraft noise exposure with a resolution of 100m-by-100m based on effective radar flight track information, aircraft noise profiles and environmental characteristics such as terrain or prevalent winds (see Boes and Nüesch (2011) for additional details). In our analyses, we use $L_{eq}^{d}(16)$ and $L_{eq}^{n}(1)$ as noise measures. L_{eq} is a metric that indicates the corresponding steady sound level for a given time interval that would produce the same energy as the actual time-varying noise intensity. $L_{eq}^{d}(16)$ is the average noise intensity for the 16 hours interval between 6 am and 10 pm, whereas $L_{eq}^{n}(1)$ is the noise intensity for the one hour interval between 10 and 11 pm. The units of measurement are A-weighted decibels, abbreviated by dB(A). The annual noise measures are available for the years 1999 to 2005.

3.2 Health data

Information on individual health outcomes and personal background is extracted from the *Swiss Household Panel* (SHP). The SHP is an annual survey of the Swiss population with a total of about 5'000 households and all their members aged 14 years and older. The data are collected using computer assisted telephone interviews (CATIs) held from September to February each wave. For detailed information about the SHP, its study design, sampling frame, and data quality, see Voorpostel *et al.* (2010). For this study, we focus on individuals who reside in the canton of Zurich as this is the most relevant area when evaluating the effects of aircraft noise on health around Zurich airport. The SHP captures individual health by a variety of questions that concern both specific and general health outcomes.

3.3 Linking aircraft noise and individual health

The original SHP data only indicate a household's canton of residence. However, the *Swiss Centre of Expertise in the Social Sciences*, which runs the SHP, gratefully sent us exact household addresses (community, zipcode, street name and number) after signing a data confidentiality agreement. We transformed this information into Swiss grid coordinates using the webpage http://tools.retorte.ch/map/. For only 4.5 percent of the cases, coordinates could not be determined exactly based on street name and number, either due to misspelling, or because the webpage did not program the respective address into the system. In these rare cases, we used the coordinates of the population-weighted center of gravity of the address' zipcode, provided by the geographical information system (GIS) software of *MicroGIS*.

The SHP health data is then linked to aircraft noise data based on the point in the 100m-to-100m grid that is nearest to the exact location of the household. Given the availability of noise and household data, this is the best match one can possibly do and provides a very accurate picture of aircraft noise exposure at the place of residence for each individual. This is important as environmental noise tends to be a local phenomenon and imprecise matching inevitably leads to problems of measurement error.

3.4 Flight regime changes

We explore two changes in flight regulations at Zurich airport as our source of exogenous variation in aircraft noise exposure. Zurich airport has three different runways and thus aircraft could in principle start and land in six different directions. Figure 1 gives an overview of the airport and illustrates the relative frequencies of landing and starting aircraft by flight direction in 2002. Aircraft generally land from the northwest on runway 14 and start in direction west on runway 28. Less frequently, runway 16 is used for takeoffs and landings. In case of strong west wind, aircraft are redirected to land from the east on runway 28 and start in direction north from runway 32. In case of a strong east wind, aircraft have to start on runway 10 in direction east.

— Insert Figure 1 about here —

The first change in flight regulations happened during summer 2000. The runway 10/28 had to be closed from May 29 to July 31, 2000, due to the construction of a new terminal (Midfield Dock E). Instead of starting to the west, aircraft had to be redirected to start in direction south on runway 16. Figure 2 shows the monthly number of departures on the basis of airport operation time, i.e., from 6 am to 12 am, separately for each runway. We observe that the number of west departures dropped to zero and the number of south departures tripled in June and July 2000 due to the closure of runway 10/28.

— Insert Figure 2 about here —

The second important change happened in 2003 and primarily affected landings. Because Zurich airport is located relatively close to the Swiss-German border (dark dashed line in Figure 1), landing aircraft fly at an altitude of less than 4,000 feet over German communities. In order to protect these communities from "Swiss" aircraft noise, the German government issued a binding decree on April 17, 2003 that prohibited landings from the north in the early morning (6 to 7 am on weekdays and 6 to 9 am on weekends) and the late evening (9 pm to 12 am on weekdays and 8 pm to 12 am on weekends). As a result, landings had to be redirected to runway 28 (from the east) because at that time the flight regulations did not allow any other direction. On May 21, 2003 the *Federal Office of Civil Aviation* decided to permit landings from the south on runway 34, starting from October 30, 2003. The new flight regulation (which has not been changed since) states that aircraft landing in the early morning hours approach from the south, and aircraft landing in the late evening hours approach from the east. Exceptions are only allowed in case of strong wind or fog, or in the case of emergency flights (Flughafen Zürich AG, 2011a).

— Insert Figures 3 and 4 about here —

Figure 3 illustrates the monthly number of landings in the early morning by flight direction. In 2002 landings in the early morning were mainly operated from the north, between April 2003 and October 2003 from the east, and thereafter from the south. The temporary increase of landings from the north in October 2005 was due to the test phase of a new flight path from the northwest over Swiss territory. As the new flight path had to be carried out by a visual approach instead of using the otherwise prevailing instrument landing system, it was denied for safety reasons by the *Federal Office of Civil Aviation*.

A similar decrease of landings from the north can also be observed in the late evening (see Figure 4). After 2003, landing aircraft between 9 pm and 12 am were redirected to land from the east instead of the north. The temporary reductions of late landings from the east in winter can be explained by weather conditions and the corresponding safety regulations. In winter the weather around Zurich airport is often very foggy, and safety regulations prescribe that landing aircraft have to approach from the south when visibility is less than 4300 m but more than 750 m. If visibility is less than 750 m, landing aircraft have to approach from the north.

— Insert Figures 5 to 7 about here —

The two flight regime changes substantially altered aircraft noise around the airport. Figures 5-7 illustrate the local exposure by means of noise contours derived from the detailed EMPA noise data. Figure 5 shows the daytime 16-hours equivalent steady noise level from 6 am to 10 pm, $L_{eq}^{d}(16)$, for the year 2002, i.e., the year in between the two flight regime changes. The dark regions correspond to the highest levels of average noise exposure, the white regions to the lowest. As would seem natural, the areas directly surrounding the airport and in direction of the three runways are the most heavily exposed to aircraft noise.

Figure 6 shows the noise changes in $L_{eq}^{d}(16)$ between 1999 and 2000 caused by the first flight regime change, while Figure 7 illustrates the changes between 2002 and 2004 caused by the second flight regime change. Both figures indicate that the region in the southeast of the airport is affected the most by the change in flight regulations. The noise increase in the south between 1999 and 2000 is due to departing aircraft in this direction, while the noise increase between 2002 and 2004 is due to landing aircraft from the south.

4 How does aircraft noise affect individual health?

4.1 Identification strategy

The main contribution of this paper is to provide new and compelling evidence on the causal effect of aircraft noise on health. In this paper, we identify a causal effect of aircraft noise on health using the following model framework

$$H_{it} = f(N_{it}, X_{it}, \delta_t, \alpha_i, \varepsilon_{it}) \tag{1}$$

where H_{it} denotes health of individual i at time t, N_{it} denotes exposure to aircraft noise. X_{it} is a vector of observed background variables, and δ_t are year fixed effects. α_i summarizes all time-constant and ε_{it} the remaining time-varying unobserved characteristics affecting health. The function $f(\cdot)$ translates health inputs into outputs and will typically be a step function because of the discreteness of most of our outcomes.

In order to provide a broad picture of the possible effects of aircraft noise on health, we use various health outcomes, including general and specific domains. Specific health outcomes are considered by using three indicators for regular suffers from *sleeping problems*, *weakness and weariness*, and *headaches*.[3] For a more general health assessment, we use a self-rated statement

[3]The three indicators are based on questions of the type "Over the last year, have you suffered at least once a month from any of the following disorders or health problems? (yes/no)". The wording has changed in the 2004/05 wave to "During the last 4 weeks, have you suffered from any of the following disorders or health problems? (not at all, somewhat, very much)". We used a consistent yes/no coding and accommodate changes in answer behavior by adding year dummies to our models.

regarding how the respondent currently feels (on a five-point scale). We constructed a binary indicator for *bad health status* from this question that equals one if the respondent states feeling so-so, not very well, or not well at all, and that equals zero otherwise (which corresponds to feeling well, or very well). In addition, general health evaluations are considered by the *number of days affected by health problems* (in terms of carrying out usual activity at work or in the household) and the *number of doctor consultations* in the previous 12 months. The number of doctor consultations provides a more objective evaluation of general health.

Given the nature of these variables, we expect stronger effects of aircraft noise on the specific measures like sleeping problems and headaches. The effects on general health or the number of doctor visits are likely to be weaker and possibly moderated by the specific domains. For the exposure to aircraft noise, we distinguish between daytime noise (6 am to 10 pm) and nighttime noise (10 to 11 pm). On the one hand, we expect daytime noise to have stronger effects on health because it captures the longer time frame. On the other hand, the nighttime noise measure captures a more sensitive time frame when most people go to bed and when noise is expected to be particularly disturbing with regards to sleeping problems and other health outcomes.

The vector of control variables X_{it} includes log household income, an indicator whether the respondent changed job in the last year, the number of kids, and civil status (all time-varying), plus gender, age, education, and an indicator for swiss nationality (the latter all time-constant or collinear with individual and time fixed effects). For comparability reasons, we require non-missing information on all covariates, including the job and moving history. Year fixed effects (δ_t) control for common time trends in noise and health.

Econometrically, we tackle the endogenous exposure to noise using two features of our data: individual panel data and sufficient exogenous within variation in noise exposure due to the flight regime changes. The panel structure allows us to estimate fixed effects (FE) models that do not impose strict assumptions on the relationship between N_{it} and α_i. If noise sensitivity is a driving force of residential choice and a health determinant, and if noise sensitivity is a constant phenomenon (and thus part of α_i), then using individual fixed effects will entirely eliminate the bias in noise effects that arises from this confounding factor. The reason is that in FE effects models, the time-constant α_i is removed by applying some transformation, like taking first differences, within transformation, or conditioning on sufficient statistics (e.g., Hsiao, 2003; Wooldridge, 2010). In our case, we employ FE logit models for all binary health outcomes, and FE Poisson models for the number of doctor consultations and the days affected by health problems. As we consider only individuals who did not change residence during the study period, individual FE also control for time-constant spatial heterogeneity affecting health. Sensitivity tests reveal, however, that the results remain virtually the same if we do not condition on non-moving people.[4]

While FE models are attractive given that potential confounders are time-constant, two major problems arise in our context. First, the exposure to aircraft noise, on an average year-to-year basis in particular, is not varying much over time. As a consequence, using a FE strategy removes the bias from time-constant confounders, but it also removes almost all the variation in the explanatory variable of interest. Second, one might question whether noise sensitivity and idiosyncratic vulnerability to noise in general are time-constant, or whether they exhibit some variation over time. If so, then a FE model only removes part of the bias in the estimated noise effects. The key advantage of our data is that we can rely on two quasi-experiments that, one the one hand, generate sufficient variation in noise over time, and on the other hand, create within variation we argue to be exogenous.

— Insert Table 1 about here —

Table 1 shows several statistics supporting this argument. The mean noise exposure during the day is about 41 dB(A), and about 36 dB(A) during the night hour 10 pm to 11pm. The overall variance for the time span 1999-2005 is more than 10 times larger than the within

[4]We do not observe any significant differences in health and noise exposure between non-movers and movers, indicating that both noise sensitive and noise insensitive people moved during the study period. Whereas noise sensitive people are likely to move into quieter regions, noise insensitive people may move into noisier regions due to other reasons than noise, like shorter commuting times, cheaper rents, or a new working place.

individual variance. This can be explained by the fact that the overall variance captures different people living in different places. However, when applying FE, the within variance is more interesting. The within variance of the entire sample between 1999-2005 is about 2.8 for daytime noise and reduces to 0.1 to 0.4 for years not affected by the changes in flight regulations (2001/02 and 2004/05). About the same can be observed for nighttime noise. The within variance of nighttime noise is 4.0 between 1999-2005 and only 0.9 and 1.2 for the unaffected years. Thus, 70 percent and more of the within variance can be explained by the exogenous changes in flight patterns.

4.2 Descriptive statistics

Table 2 shows the descriptive statistics of health variables given our sample of 1,902 individuals and 4,846 person-year observations. 15 percent experience regular sleeping problems, 19 percent experience weakness and weariness, and 22 percent regular headaches. About 12 percent report a bad health status. Individuals go about three times to the doctor per year, and the average number of days affected by health problems is about three. These numbers are relatively stable over time with less than ten percent year-to-year variation. To avoid problems with outliers of the count variables *number of days affected by health problems* and *number of doctor consultations* without losing observations, we winsorized at the 99th percentile by setting outlying values to the 99th percentile.

— Insert Table 2 about here —

4.3 Estimated noise effects

Table 3 summarizes the main results of the paper. We estimate the effects of aircraft noise on health using different models, health outcomes, and noise measures. Columns (1) and (2) show the estimated noise coefficients and cluster adjusted standard errors in parentheses from pooled logit and Poisson models for the binary and count health outcomes, respectively.

Column (1) refers to a basic model specification that includes the noise measure and year fixed effects as the only right-hand side variables. Column (2) adds the control variables. Columns (3) and (4) display the results from the same type of models, but including individual fixed effects. Panel A shows the results for the effects of daytime noise, Panel B for nighttime noise.

— Insert Table 3 about here —

The results of the pooled models suggest no effects of aircraft noise on health. All coefficients are very small and statistically insignificant. In contrast to the pooled models, the FE models suggest a significant increase in sleeping problems and headaches caused by additional daytime aircraft noise and a significant increase in sleeping problems and weakness/weariness caused by additional nighttime noise. The effects on general health outcomes remain insignificant in the FE models.

Given the small magnitude of the estimated coefficients, the relative changes in these quantities for a 1 dB(A) increase in noise exposure can be approximately read off Table 3 after multiplying by 100 percent. Thus, a FE logit coefficient of 0.0742, for example (first entry in column (3)), means that the odds of having sleeping problems relative to not having them increase by about 7.42 percent with an additional 1 dB(A) of daytime noise.[5]

Overall, the FE models suggest, on the one hand, that aircraft noise has a detrimental effect on specific health, such as sleeping problems, weakness/weariness, and headaches. This is what we would expect given that these domains are very sensitive to environmental disturbances. On the other hand, we find very small and insignificant effects on general health outcomes, like the health status of a person, the more objective number of doctor consultations, and the number of days affected by health problems. These health outcomes are suspected to be unaffected by aircraft noise because they reflect general assessments of health with noise exposure being just

[5]In logit models, the probability of a positive outcome is modelled as $P(Y=1|X) = \exp(X\beta)/[1+\exp(X\beta)]$ and the odds are given by the ratio $P(Y=1|X)/P(Y=0|X) = \exp(X\beta)$. In Poisson models, the conditional expectation function is given by $E(Y|X) = \exp(X\beta)$. The relative changes in the odds or the conditional mean for a *ceteris paribus* unit change in the k-th regressor are in both cases given by $100\% \cdot [\exp(\beta_k) - 1]$, which does only depend on the coefficient β_k of that regressor.

one of multiple determinants. The insignificant effect on the number of doctor consultations can be explained by the costs involved due to the mandatory yearly deductibles between CHF 300 (USD 333) and CHF 2500 (USD 2778) in Switzerland.

The fact that the detrimental impact of aircraft noise on sleeping problems, weakness and headaches is significantly larger in the FE models than in the pooled models is consistent with our argument that people self-select into the location of residence, and exposure to noise, based on their individual vulnerability and noise sensitivity in particular. As noise sensitive people are more prone to sleeping problems and weakness (Fyhri and Klaboe, 2009) and tend to live in quieter neighborhoods, pooled models underestimate the true causal effect of aircraft noise on these health outcomes. Assuming that noise sensitivity is a time-constant personality trait, FE models correct for this type of sorting bias and lead to an unbiased estimation of the causal effect.

The inclusion of controls does not alter our results. In the pooled models, the added controls do not really help to mitigate the sorting bias.[6] In the FE models, the results are stable even if we would suspect that the noise-health relationship is confounded by time-varying variables such as job change, income shocks, or divorces. This is re-assuring for our identification strategy, because it supports our argument of exogenous variation in aircraft noise once individual and time fixed effects are controlled for, and it confirms our causal interpretation of the estimated effects of aircraft noise on health in column (3) of Table 3.

4.4 Valuation of noise effects on health

Having documented that aircraft noise significantly increases sleeping problems, weakness, and headaches, the question of how to value these effects arises. Two common approaches to value health effects in monetary terms is the contingent valuation method (CVM) and the life satisfaction approach (LSA). The CVM elicits monetary valuations of health by directly asking the people how much they are willing to pay for the reduction or elimination of a health

[6]Even though a few control variables (e.g., Swiss and civil status) correlate with both health outcomes and noise exposure, the correlations become insignificant conditional on the year fixed effects.

risk (Hanley *et al.*, 2003). The LSA uses life satisfaction data and regresses subjective life satisfaction on the health risk under examination, income and the typical controls. Using the coefficients for the health risk and income, the implicit willingness-to-pay is then calculated based on the trade-off ratio between the health risk and income that keeps subjective life satisfaction constant (Ferrer-i-Carbonell and van Praag, 2002; Groot and van den Brink, 2006; Mentzakis, 2011).

While widely used, both approaches have severe limitations. The hypothetical nature of contingent valuation surveys may lead to strategic answering and inflated estimates as responses do not have any consequences for the survey individuals (Hanley *et al.*, 2003; Groot and van den Brink, 2006). The weakness of the LSA is its assumption of a positive life satisfaction-income-sensitivity, even though numerous studies (e.g., Easterlin, 1995; Oswald, 1997) have shown that over time life satisfaction does not grow with income (a finding we can confirm with our panel data).

Instead of using the CVM and LSA as stated-preferences methods, we use hedonic pricing as revealed-preferences method to value health risks (see also Davis, 2004). Hedonic pricing is based on the idea that the utility of consuming a composite product, like housing, is determined by the utility associated with its constituent parts (Rosen, 1974). Technically, the price of a house is regressed on its characteristics (like the number of rooms and aircraft noise), and economic values are derived from the coefficients estimated in the regression.

Using a hedonic price model and a large representative and longitudinal sample of rental apartments around Zurich airport, Boes and Nüesch (2011) estimate that aircraft noise reduces apartment rents by about 0.5 percent per additional decibel of daytime noise, controlling for unobserved apartment heterogeneity and observable time-varying confounders like the apartment's age. Thus, the willingness to pay for an apartment decreases if the exposure to aircraft noise increases because quietness is considered a valuable good and individuals either consciously or unconsciously take noise exposure and the associated adverse health effects into account when applying for a new apartment. The Swiss rental market is well-functioning. In

2000 two thirds of the Swiss population rented accommodation built and owned by landlords (Boes and Nüesch, 2011).

In the following, we use the 0.5 percent noise discount and data on the number of apartments and the yearly rents to derive an estimate of overall aircraft noise costs in the canton of Zurich. We use the following formula for our calculation:

$$Noise\ costs = (\sum_i 0.005 \cdot \left(L^d_{eq}(16)_i - 30\right) \cdot \#apart_i \cdot rent_i)/\#residents \tag{2}$$

where $L^d_{eq}(16)_i$ is the average daytime noise exposure in the 16 hour interval from 6 am to 10 pm in 2000 of the population-weighted center of gravity for each of the 151 communities i in the canton with noise exposure above 30 dB(A). 30 dB(A) is a threshold value below which no effects on sleep (WHO, 2009) and rents (Boes and Nüesch, 2011) have been observed. $\#apart_i$ denotes the number of rental and property apartments in community i from the 2000 census of population. $rent_i$ is the average rental price for apartments in community i derived from the dataset of Boes and Nüesch (2011). The noise discount of 0.5 percent is multiplied by aircraft noise above the threshold value of 30 dB(A) and the yearly rental volume in community i. After adding up the figures for all communities in the canton of Zurich, the sum is divided by the total number of $residents$ living in the canton.

In 2000, the canton of Zurich counted about 1.2 million people living in 600'503 apartments with an average yearly rent of about CHF 19'487. Introducing the exact community-specific numbers into equation (2), the average yearly noise discount is about CHF 683.4 (around USD 400 at that time) per person.

On the one hand, this estimate may undervalue the health-related noise costs as housing tends to be more expensive in the property market than in the rental market. On the other hand, this estimate may overvalue the health-related noise costs because a lack of aircraft noise does not only improve health but also general well-being. Overall, we consider our valuation of noise effects as plausible.

5 Conclusion

This paper makes two general and one specific contributions to the literature. First, our results indicate that residential sorting is of major importance in epidemiological studies, and environmental economics in general. People tend to self-select into residence based on preferences for the variable of interest (here, a lack of aircraft noise). These preferences are likely correlated with the outcome (here, health). We find that the impact of noise on health is substantially larger in FE models than in pooled models. As individual FE control for a person's unobserved noise sensitivity, the differences in estimates indicate that noise sensitivity is negatively correlated with actual noise exposure (noise sensitive people select quiet neighborhoods) and associated with poor health.

Second, we demonstrate that the mix of fixed effects and quasi-experiments is very powerful to identify a causal effect from field data, and the effect of aircraft noise on health, specifically. This approach strictly contrasts our work from all previous related field studies. Individual FE control for time-constant and health relevant differences between individuals. Such heterogeneity includes, for example, pre-determined health through genetic predisposition. To identify a relationship in FE models, sufficient within-variation is required. Quasi-experiments may create such within-variation and are therefore crucial as a source of identification. In our context, two exogenous changes in unique high-resolution noise data are explored to minimize the bias through measurement error and to increase the credibility of the analysis.

Third, we contribute more specifically by providing quasi-experimental evidence of the effect of aircraft noise on health for people living aroung Zurich airport. We find that aircraft noise significantly increases sleeping problems, weakness/weariness, and headaches. Based on noise-related reductions of rents around Zurich airport, we estimate the yearly costs of aircraft noise to be around USD 400 per person living in the canton of Zurich.

Acknowledgements

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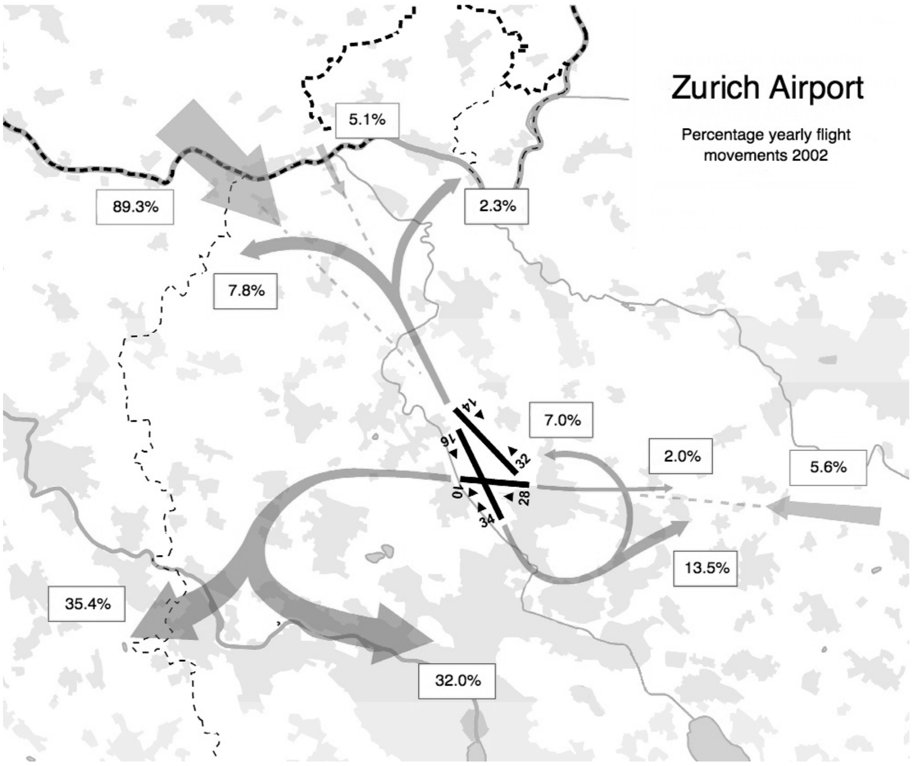
Tables and Figures

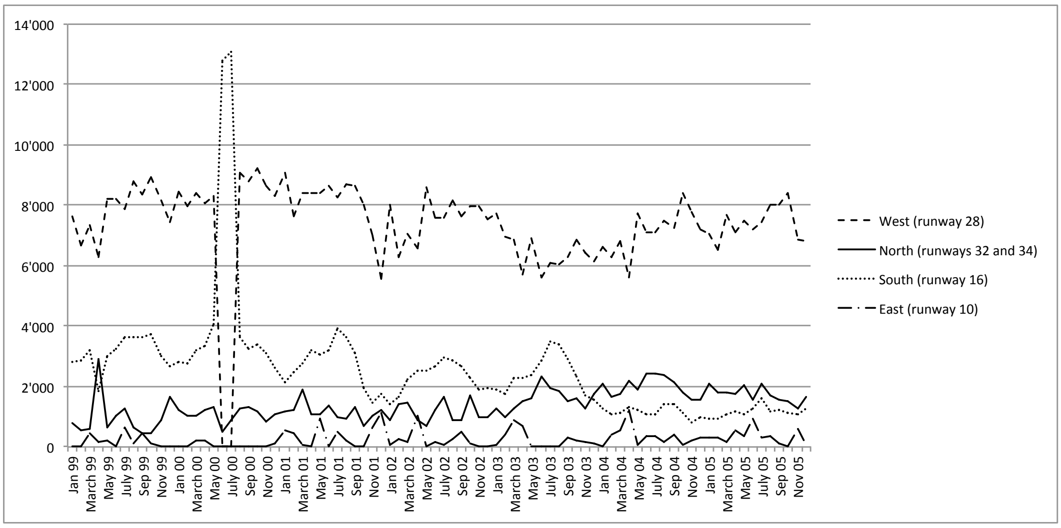
Figure 1: Zurich airport and flight paths in 2002



Notes: Percentage occupancy of landing and takeoff routes in 2002. Light grey are settlement areas. Thick dashed line marks Swiss-German border. Thin dashed line marks cantonal border. North/south runway 16/34, northwest/southeast runway 14/32, east/west runway 10/28.

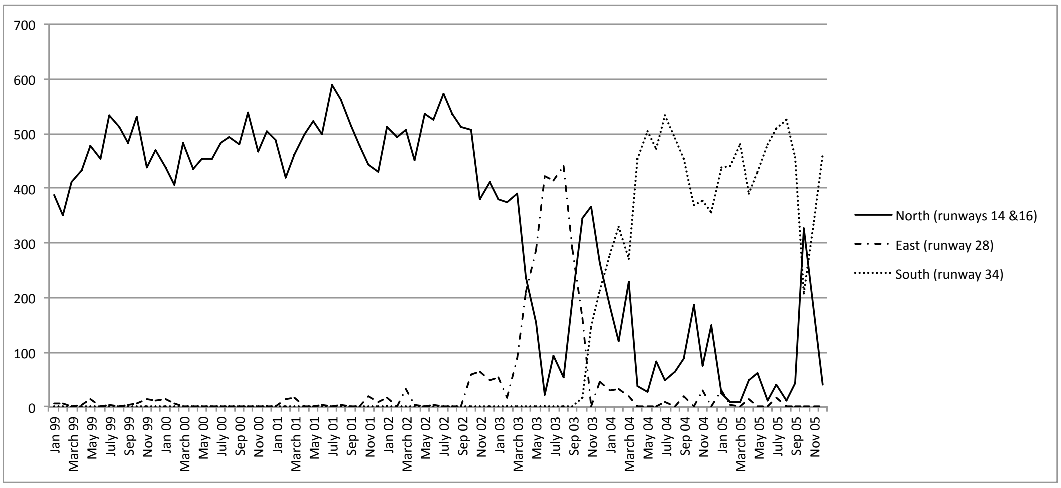
Source: Flughafen Zürich AG (2011b, p. 50) adapted to 2002 figures.

Figure 2: Monthly number of departures over the whole day



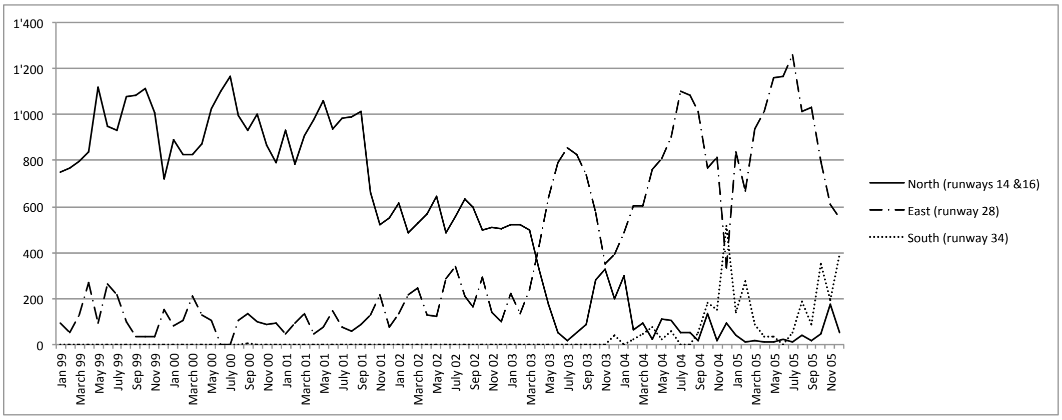
Source: Flughafen Zürich AG, own calculations.

Figure 3: Monthly landings from 6 am to 7 am



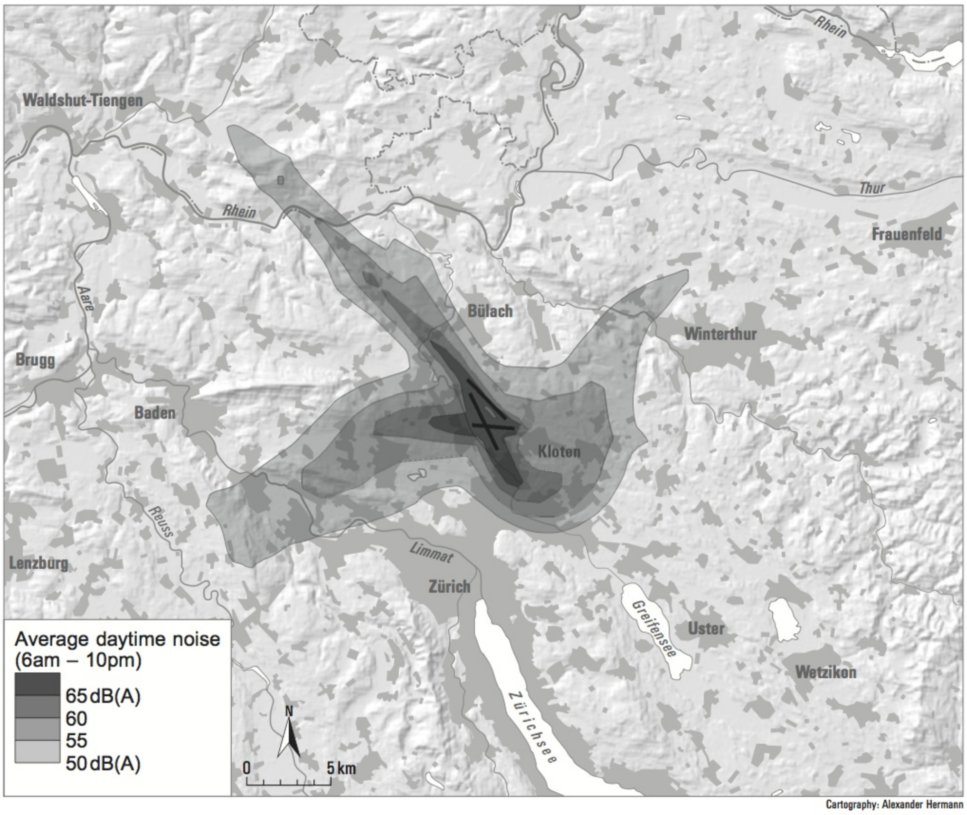
Source: Flughafen Zürich AG, own calculations.

Figure 4: Monthly landings from 9 pm to 12 am



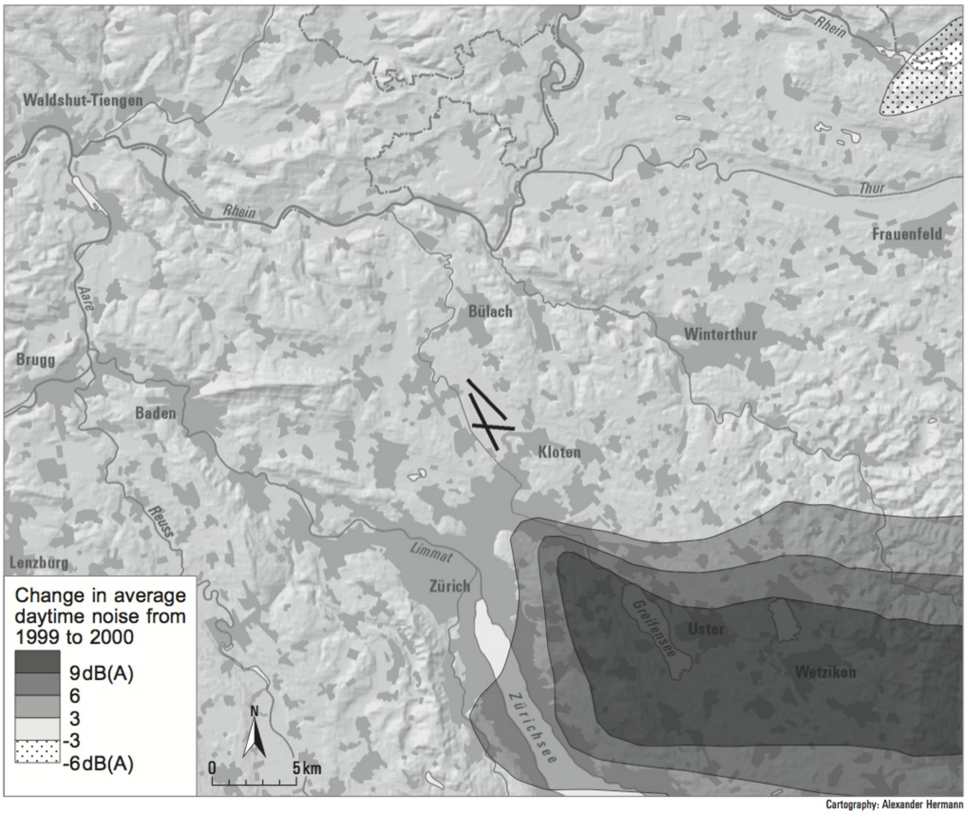
Source: Flughafen Zürich AG, own calculations.

Figure 5: Daytime noise exposure in 2002



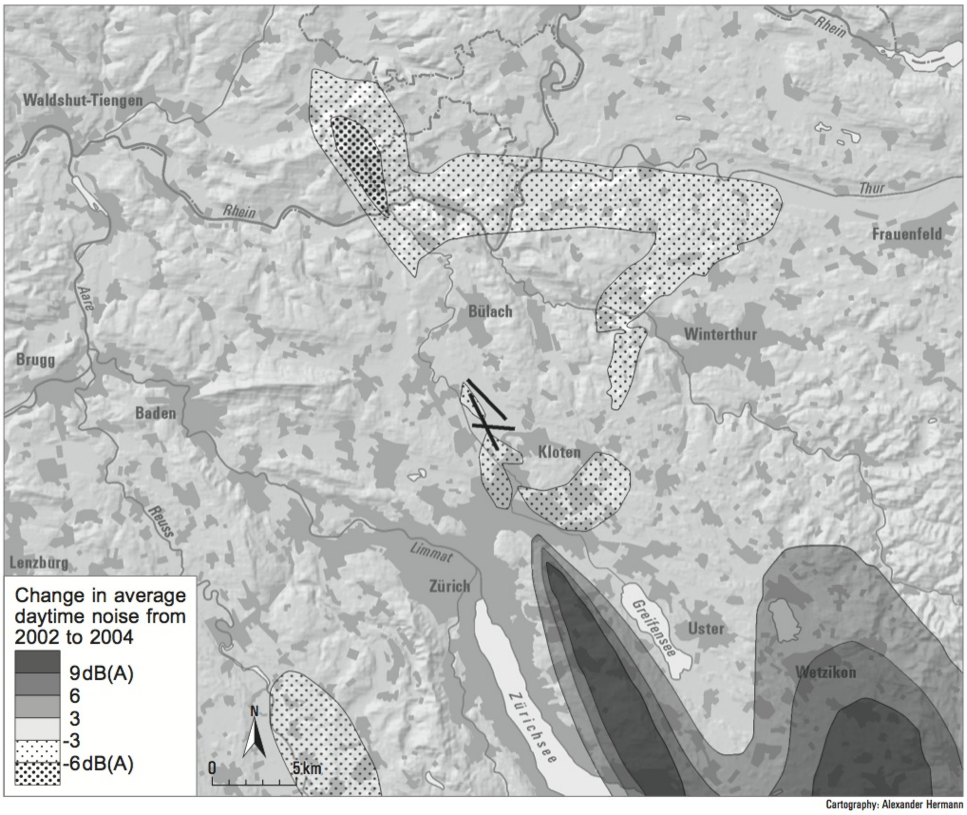
Source: EMPA, own calculations. Daytime noise $L_{eq}^{d}(16)$ for the 16 hour interval 6 am to 10 pm in 2002.

Figure 6: Changes in daytime noise exposure from 1999 to 2000



Source: EMPA, own calculations. Changes in daytime noise $L_{eq}^{d}(16)$ for the 16 hour interval 6 am to 10 pm from 1999 to 2000.

Figure 7: Changes in daytime noise exposure from 2002 to 2004



Source: EMPA, own calculations. Changes in daytime noise $L^{d}_{eq}(16)$ for the 16 hour interval 6 am to 10 pm from 2002 to 2004.

Table 1: Variation of noise

		Mean	Variance		
			1999-2005	2001/02	2004/05
Daytime noise	Overall	40.5	69.8	89.5	52.6
	Within		2.8	0.1	0.4
Nighttime noise	Overall	35.6	64.0	76.3	47.2
	Within		4.0	0.9	1.2

Source: EMPA, own calculations. *Notes:* Daytime noise is the L_{eq} equivalence metric that measures average aircraft noise exposure for the 16h interval from 6 am to 10 pm. Nighttime noise is average aircraft noise exposure for the 1h interval from 10 to 11 pm. Mean values are in dB(A), variation measured as sample variance.

Table 2: Summary of health outcomes

	Fraction/Mean (Std. Dev.)
Sleeping problems	15.3%
Weakness/weariness	19.0%
Headaches	21.6%
Bad health status	11.5%
Number of doctor consultations	2.69 (4.09)
Days affected by health problems	4.44 (11.88)
Number of observations	4,846
Number of individuals	1,902

Source: Swiss Household Panel (SHP), own calculations. *Notes:* Sleeping problems, headaches, and weakness/weariness indicate regularly felt health problems (yes/no). Bad health status indicates self-rated health worse than mid point on 5-point scale.

Table 3: Effects of aircraft noise on health

	Pooled models		Fixed effects models	
	(1)	(2)	(3)	(4)
A. Effect of daytime noise on				
Sleeping problems	0.0040	0.0016	0.0742**	0.0772**
	(0.0064)	(0.0067)	(0.0361)	(0.0371)
Weakness/weariness	-0.0033	-0.0035	0.0403	0.0388
	(0.0056)	(0.0059)	(0.0335)	(0.0342)
Headaches	0.0056	0.0043	0.0970**	0.0967**
	(0.0057)	(0.0059)	(0.0419)	(0.0421)
Bad health status	-0.0033	-0.0058	0.0123	0.0181
	(0.0066)	(0.0069)	(0.0348)	(0.0354)
Number of doctor consultations	0.0058	0.0045	-0.0029	-0.0044
	(0.0037)	(0.0036)	(0.0117)	(0.0114)
Days affected by health problems	0.0030	0.0019	0.0201	0.0192
	(0.0054)	(0.0054)	(0.0256)	(0.0254)
B. Effect of nighttime noise on				
Sleeping problems	0.00080	0.0062	0.0655**	0.0734**
	(0.0068)	(0.0070)	(0.0294)	(0.0307)
Weakness/weariness	-0.0003	-0.0003	0.0544**	0.0555**
	(0.0058)	(0.0060)	(0.0257)	(0.0262)
Headaches	0.0069	0.0053	0.0452	0.0462
	(0.0061)	(0.0062)	(0.0345)	(0.0345)
Bad health status	-0.0028	-0.0042	-0.0012	-0.0009
	(0.0073)	(0.0077)	(0.0278)	(0.0290)
Number of doctor consultations	-0.0015	0.0005	0.0010	-0.0003
	(0.0037)	(0.0037)	(0.0094)	(0.0093)
Days affected by health problems	-0.0020	-0.0027	0.0115	0.0112
	(0.0056)	(0.0056)	(0.0216)	(0.0216)
Time fixed effects	yes	yes	yes	yes
Control variables	no	yes	no	yes
Individual fixed effects	no	no	yes	yes

Source: Linked SHP/EMPA data, own calculations. *Notes:* Table shows the estimated coefficients and the cluster adjusted standard errors in parentheses of 32 different pooled/FE logit regressions for binary health outcomes and of 16 different pooled/FE poisson regressions for count variables. Variables are described in Table 2. FE controls include log income, job change, number of kids, civil status. Pooled controls additionally include gender, age, education, and swiss nationality.

*** $p < 0.01$ ** $p < 0.05$ * $p < 0.1$